ALLIS-CHALMERS Electrical REVIEW

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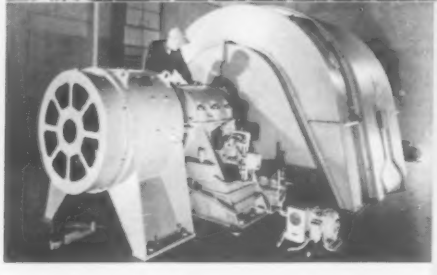
Better than Rebuilding Transmission Lines



Pacific Coast system uses 50,000-kva hydrogen-cooled condenser (top view), and 20,000-kva air-cooled unit (bottom view).

Besides minimizing losses, hydrogen cooling results in a design suited to outdoor operation. Air-cooled units can also be built for outdoor use, and for industrial power-factor-correction applications.

Regulex amplifier control, which acts as both regulator and pilot exciter, is available for all synchronous condenser ratings.

Regulex is an Allis-Chalmers trademark.

FOR WIDESPREAD power systems, synchronous condensers can frequently be used in place of added or larger transmission lines. This is possible because, by supplying reactive kva, they assure efficient use of power lines.

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Electrical REVIEW

THE COVER

LOOKING THROUGH two 3-foot square panes of heavy plate glass and 4 feet of zinc bromide solution, the operator of this 22-million electron volt betatron is watching the patient while controlling the amount and depth of radiation. This work is being done at an eastern medical research center, to determine clinical procedures for cancer therapy. Unlike conventional X-ray machines, the betatron emits an X-ray beam which increases in intensity after entering the body. Experimentation and clinical experience with several units in the United States and Canada since 1946 have been very encouraging — indicating that greater destruction of deep seated malignancies can be accomplished with less damage to healthy tissues.

A-C Staff Photo by M. Durante

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ULTRASONIC TESTING of Spindle and Rotor Forgings

UNDER TEST, this large forging is rotated slowly at uniform speed so that every cubic inch of its volume can be inspected.

by **ROBERT G. MATTERS**
Research Supervisor
Research Laboratory
Allis-Chalmers Mfg. Co.

Bouncing sound that can locate flaws at any depth assures highest quality steam turbine generator rotating elements.

EARLY STEAM TURBINE SPINDLES and generator rotors were made from solid forgings of low or medium carbon steels in the annealed condition. As turbine and generator units increased in capacity, much larger forgings produced from larger ingots became necessary. Larger ingot size, and in some cases a reduction in the amount of hot working, increased the possibility of center defects. Subsequently, the higher stresses in still larger units necessitated a change from carbon steel to alloy steels of higher strength. These alloy steels are somewhat more difficult to handle and have a greater tendency to develop thermal cracks and flakes.

Because of stresses developed in the larger spindles and rotors during operation, forgings of the highest quality must be used. To assure high quality forgings, chemical analysis, heat treatment and mechanical properties are carefully controlled. In addition, various types of inspection, principally bore inspection and ultrasonic testing, are used.

About 30 years ago, bore inspection of turbine spindles and generator rotors became general practice. In this method of inspection a hole is bored through the length of the forging and finished by reaming or honing. Then the bore is examined visually with a periscope, or telescope and mirror.

Scope of bore inspection

Excessive center porosity, bursts and major cracks which intersect a properly finished surface can be readily observed in the bore. However, visual inspection does not always reveal flakes, which are very tight cracks usually less than one inch in maximum dimension, even if they occur on the bore surface. Flakes which may occur at some distance from the bore are not revealed by bore inspection even if special techniques such as magnafluxing or deep etching of the bore surface are employed.

A high local tangential stress is developed at the bore surface of a generator rotor or turbine spindle when it is rotating at operating speeds. For the smallest possible bore in a rotating disc of uniform thickness, the local stress at the bore surface is twice that of an unbored disc. The average tangential stress, however, is only increased 10 percent by a bore, 10 percent of the outside diameter of the disc. Overspeed tests indicate that the average tangential stress rather than the maximum tangential stress is the best measure of serious deformation or failure of a rotating forging. For this reason a small bore does not seriously reduce the strength of a forging.

In general practice, the bore diameters of forgings have been increased to remove center defects found during inspection. The bore may be simply enlarged by boring from one end, or the forging may be "bottle" bored locally by the use of special tools. The maximum bore size allowed is determined on the basis of stress or, sometimes in the case of generator rotors, on the basis of magnetic requirements. Another method used to remove defects from the bores of forgings is local grinding.

Salvage of a forging by enlarging the bore is an uncertain procedure. The operation is very time consuming, and a forging may have to be scrapped after considerable time has been spent in enlarging the bore.

How the ultrasonic reflectoscope works

Recently the ultrasonic reflectoscope has been employed for the inspection of steam turbine spindles and generator rotor forgings. Its essential components are a piezoelectric crystal, a cathode-ray oscilloscope, a very high frequency oscillator, and the associated electronic circuits.

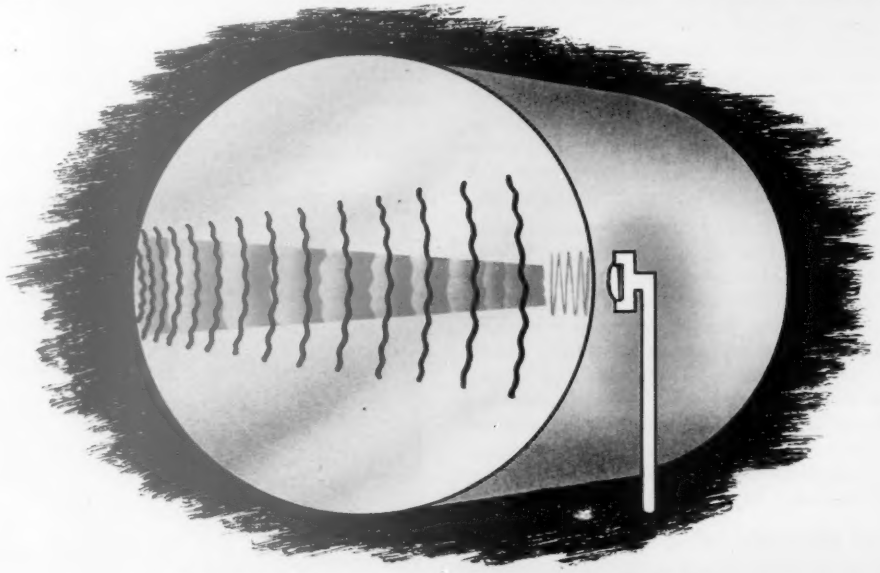
In the operation of the reflectoscope, a timing circuit triggers the oscillator, sweep, and marker circuits 60 times per second. The oscillator supplies a short high frequency electrical pulse to the piezoelectric crystal, which transforms the electrical pulse into a sound pulse of the same frequency. The sound pulse is transmitted into the forging being tested by a liquid film between the crystal and the forging. It travels through the forging as a well-defined beam and is reflected by the opposite surface, see Figure 1. If the opposite surface is perpendicular to the direction of the beam, the sound pulse is reflected back to the piezoelectric crystal. Excitation of the crystal by the sound produces an electromotive force which is amplified and fed into the vertical deflection circuit of the cathode-ray oscilloscope.

While each sound pulse passes through the forging, the sweep circuit output causes a horizontal deflection of the oscilloscope spot. Thus, the reflectoscope pattern for a homogeneous piece of material consists of a vertical deflection, designated the initial pulse, a horizontal line, and a second vertical deflection, designated the back reflection. Any discontinuity in the material will partially scatter and partially reflect the sound impulse. Consequently, depending on its size and shape, a discontinuity in the material will reduce or eliminate the back reflection and will usually reflect enough sound back to the crystal to cause a vertical deflection of the oscilloscope trace between the initial pulse and the back reflection.

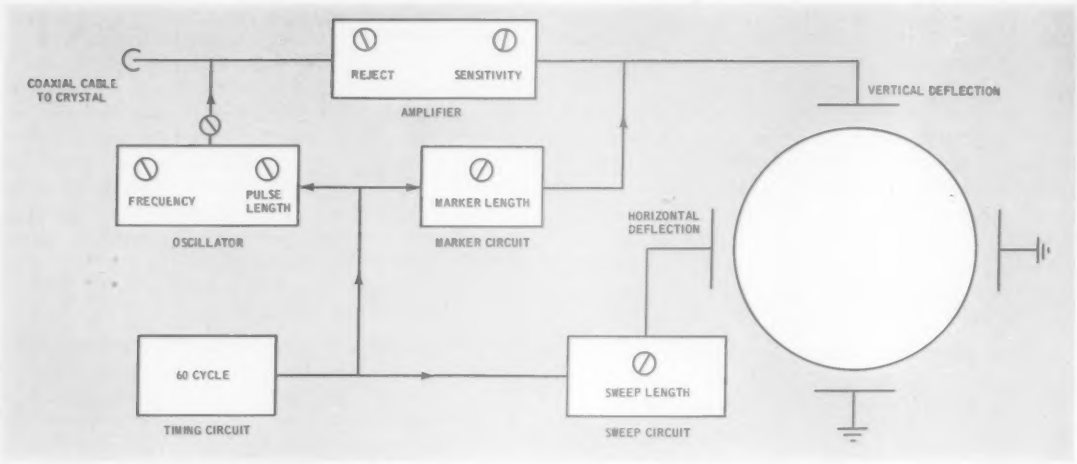
Commercially available ultrasonic reflectoscope instruments have provisions for control of frequency, sensitivity pulse length, sweep length, and marker length, as indicated in the block diagram, Figure 2. The oscillator circuit may be set for frequencies of 0.5, 1, 2.25, and 5 megacycles. A piezoelectric crystal cut to oscillate at the particular frequency selected must be employed. The crystal is connected to the oscilloscope by a suitable low-loss coaxial cable.

The sound beam produced by the reflectoscope will be partially absorbed and partially scattered while passing through the material being tested. Absorption and scattering are strongly influenced by the material being tested and, in general, are greatly increased by fine porosity or large grain size. Graphite flakes have so severe an effect that gray cast iron cannot be satisfactorily tested by the ultrasonic method.

Since absorption and scattering increase with frequency, the penetrating power of the sound beam is reduced as frequency is increased. However, the higher frequencies have the advantages that smaller defects may be observed



SIMILAR TO RADAR, sound pulses transmitted by the crystal pass through a forging and are reflected by the opposite surface. Transmitted sound waves are indicated in color, reflected waves in black. **(FIGURE 1)**



THIS SIMPLIFIED block diagram of the reflectoscope indicates the various circuits and controls. **(FIGURE 2)**

and that the sound beams do not spread as much as at lower frequencies.

Pulse length can be controlled

Another control in the oscillator circuit determines sound pulse duration within the range of approximately 20 to 100 microseconds. Usually the pulse length is set to the minimum value, since the oscilloscope deflection caused by the initial pulse masks any possible indications of defects within the first inch or two of the surface, see Figure 3. However, for very large forgings, where considerable absorption may occur, an increase in pulse length will improve penetration.

The horizontal deflection across the oscilloscope tube may represent any desired penetration, from approximately 4 inches to 20 feet in steel, and is controlled by an adjustment in the sweep length circuit. A marker circuit supplies a square wave form to the vertical deflection of the tube. By means of the control in this circuit, the time base of the square wave may be adjusted to correspond to distances of approximately ¼ inch to 12 inches in steel.

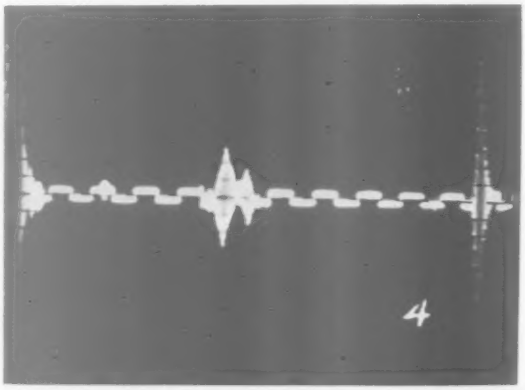
The amplifier circuit has two controls for adjusting the sensitivity of the reflectoscope to the defects. One of these controls, designated the sensitivity control, is a simple amplifier gain control. The other control, designated the reject control, distorts the response curve of the amplifier so that small indications are minimized without greatly affecting the larger indications. This control may be used to eliminate the indications caused by small inclusions known to be present in the steel, with little effect on the indications produced by larger defects. If the sensitivity control is employed to reduce the signal from small inclusions, the response to larger defects will also be reduced.

Examples of ultrasonic indications

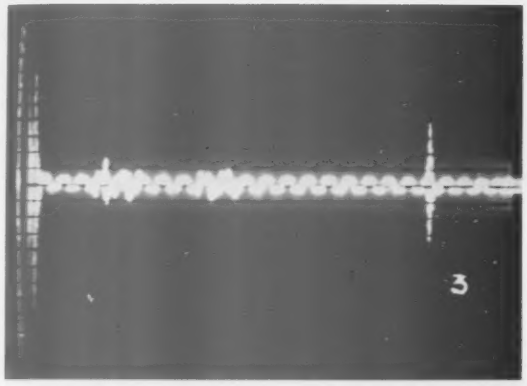
The picture at the top of page 4 shows the reflectoscope being used to test a large bored steam turbine spindle, and the oscilloscope pattern which proves it to be a sound forging. On this oscilloscope pattern the initial pulse is at the left and the back reflection representing the bore is at the right. In this case the square wave markers represent 2 inches and the distance from the surface of the spindle to the bore is 32 inches.

If any discontinuity is present in the material being tested, an indication will appear between the initial pulse and back reflection. In Figure 3 severe sonic indications may be seen at distances of 11 and 12 inches from the testing surface, with smaller indications at distances of 5½ and 10 inches from the testing surface. This is the reflectoscope pattern obtained on a 22½-inch diameter arm of an unbored steam turbine spindle forging. Figure 4 is the reflectoscope pattern of the 41½-inch diameter body of this same forging, showing indications of defects at 16, 17½, 18½, 20½, and 21½ inches from the testing surface.

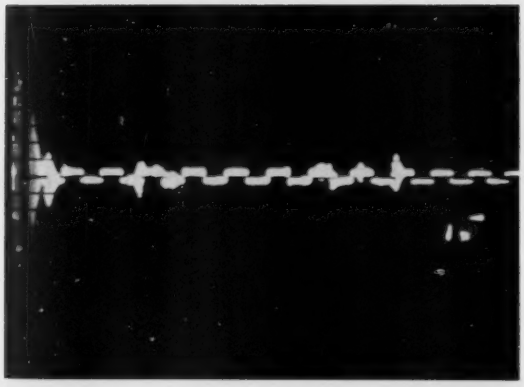
To check these ultrasonic indications a 3-inch hole was bored in the forging for conventional periscopic examina-



VERTICAL DEFLECTIONS on the oscilloscope screen result from the initial sound pulse, back reflection from the opposite surface and from any discontinuity in the material. **(FIGURE 3)**



DISTANCES from the test surface to defects or to the opposite surface, indicated by vertical deflections, are measured along the broken horizontal line produced by the marker circuit. **(FIG. 4)**



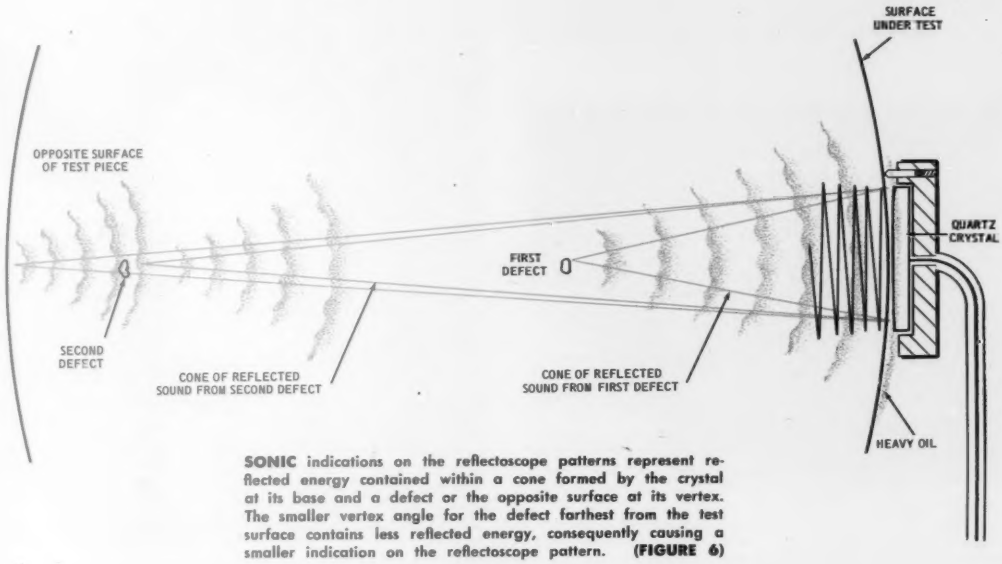
INDICATIONS caused by defects near the test surface are larger than indications for the same size defect deeper into the forging because of greater reflected energy to the crystal. **(FIGURE 5)**

tion. This examination verified that defects were present, and ultrasonic inspection of the bored forging indicated that defects extended up to 5 inches from the bore. Figure 5 is a representative reflectoscope pattern of this forging after boring and shows an ultrasonic indication adjacent to the bore, together with some smaller indications approximately 7 inches from the surface. These smaller indications represent segregated inclusions at the junction of columnar and equiaxed structures of the ingot. This forging was scrapped on the basis of ultrasonic and bore examination because the defects could not be removed from the forging within the limits of allowable bore size.

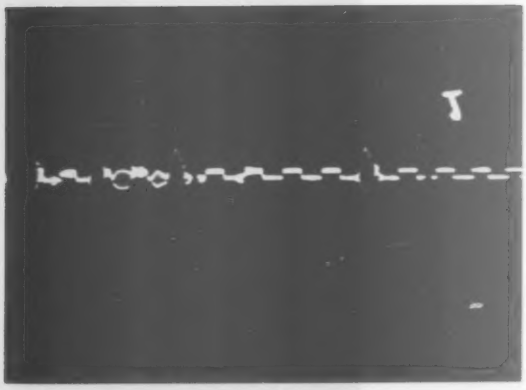
Interpreting reflectoscope patterns

The major problem in the application of the reflectoscope is interpretation of the reflectoscope patterns. Severe defects, such as pipe, forging bursts, or severe flakes, may be interpreted readily. However, inclusions and very minor porosity will certainly be confused.

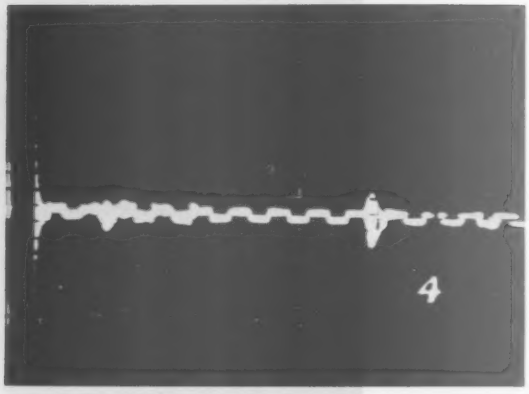
A wider cone of reflected sound having higher energy is intercepted by the crystal from an inclusion nearer the crystal than from one farther away, as shown in Figure 6. Hence inclusions near the testing surface may give disproportionally large indications, as shown in Figure 5,



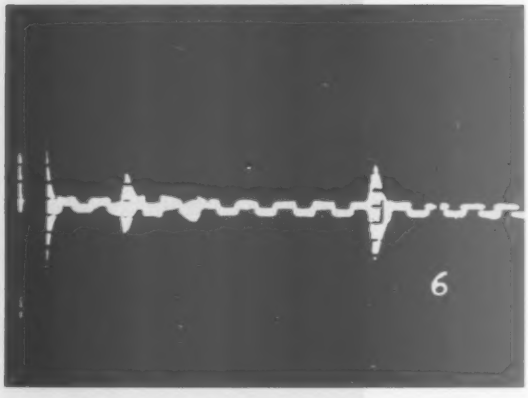
SONIC indications on the reflectoscope patterns represent reflected energy contained within a cone formed by the crystal at its base and a defect or the opposite surface at its vertex. The smaller vertex angle for the defect farthest from the test surface contains less reflected energy, consequently causing a smaller indication on the reflectoscope pattern. **(FIGURE 6)**



THIS REFLECTOSCOPE PATTERN shows indications of defects at 7, 9, 10½, 11, and 15 inches from test surface. **(FIGURE 7)**



WITHIN THE RANGE of 8 to 14 inches from the test surface, many defects are indicated by this pattern. **(FIGURE 8)**

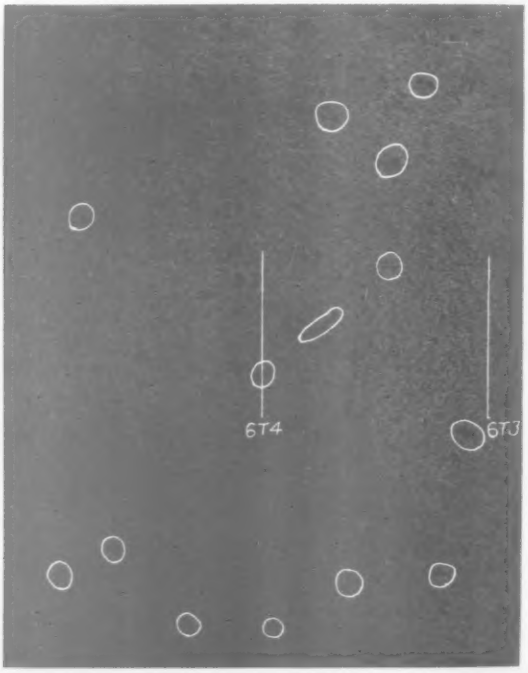


THE INITIAL sound pulse obliterates a part of this pattern which shows a severe defect at 9 inches and smaller ones at 11, 11½, and 13½ inches from test surface. **(FIG. 9)**

when a forging is tested in the radial direction. If this same zone of the forging is tested in the longitudinal direction, indications usually will not be observed because of the smaller cross section of the inclusions.

As an indication of the small defects which are revealed by the ultrasonic method, a small generator rotor forging was recently scrapped because of the ultrasonic patterns shown in Figures 7, 8, and 9. Figure 10 is a macro etched section taken from the center of this forging. It is apparent that very small ingot tears, not over ¼ inch in size and not welded by forging, caused most of these ultrasonic indications. These tears could not be observed by simple visual examination of the smooth surface prepared for macro etching.

An increasing percentage of heavy forgings is being inspected with the ultrasonic reflectoscope. This permits complete inspection of the forging's entire volume rather than of the bore and external surfaces only. Thus, the absence of concealed defects in areas inaccessible to any other inspection method is assured. To a large extent, this eliminates the need for boring steam turbine spindle and generator rotor forgings. However, some forgings are still bored to eliminate center defects. If the ultrasonic tests indicate that a bore larger than allowed for stress reasons is required to remove defects, the forging is rejected. Thus the delays caused by repeated boring of a forging which must finally be rejected are eliminated.



SHOWN ONE-HALF SIZE, this macro etched section shows small unwelded ingot tears which caused ultrasonic patterns. **(FIGURE 10)**

BOOMING INDUSTRIAL POWER DEMANDS in the Pacific Northwest led to prompt delivery and installation of these six umbrella-type 25,000-kva, 0.9-pf, 13,800-volt generators at the Rock Island Plant on the Columbia River within the past year. Driven by 34,000-hp, 100-rpm, 45-ft head Kaplan-type adjustable propeller turbines, these generators have added 150,000 kva to serve growing industrial power requirements in this rapidly expanding area.

2-WAY POWER FLOW IN FEEDER VOLTAGE REGULATORS

by **R. D. OKERBERG**
Transformer Department
Allis-Chalmers Mfg. Co.

VOLTAGES SUPPLIED from two power sources, *A* (left) and *B* (right), represented by breakers, are balanced by this regulator. **(FIGURE 1)**

Here's the answer to reverse power flow and reactive kva control problems in feeder voltage regulators between two power sources.

WHEN REGULATORS are connected in tie lines between power sources there is a possibility of power flow through the regulator from either direction. The need of special reverse power flow equipment is based on whether the power sources are used independently, simultaneously, or in combination.

Figure 1 shows a regulator installed on a line with independent power sources at each end. Power may be supplied to the loads from either source *A* at the left or source *B* at the right, but not both simultaneously. The regulator is installed with source bushings connected to source *A* to give proper regulation when source *A* is used.

When source *A* is disconnected and source *B* used, the regulator is connected backwards and does not regulate properly. A change in input voltage to the regulator from source *B* is measured by the potential transformer, but a tap change, changing the voltage to the residential load, does not affect the potential transformer. After a tap change is initiated the regulator will run to an extreme position. In this case, reverse power flow equipment is required to give proper regulator operation with power flow in either direction.

The equipment consists of a reverse power relay, an auxiliary relay that is controlled by the reverse power relay, and an additional potential transformer connected to the source side, so that voltages on both sides of the regulator can be measured. The auxiliary relay reverses the tap-changing motor and the line-drop compensator connections. It also connects the proper potential transformer into the circuit. It is sometimes desirable to provide a separate line-drop compensator so that different load center distances can be used for each direction of power flow.

Simultaneous power sources considered

When both source *A* and source *B* in Figure 1 are connected simultaneously, the two sources operate in parallel. The circuit is analogous to generators at *A* and *B*, with the regulator controlling the output voltage of generator *A*. Raising the output voltage of generator *A* causes it to furnish more reactive kva, while lowering the output voltage of generator *A* causes generator *B* to furnish more reactive kva. Under such conditions the operation of the voltage regulator may be erratic, since raising the output voltage of the regulator causes more reactive kva to flow through the regulator from source *A*. With normal line-drop compensation, increased reactive current decreases the voltage to the voltage regulating relay and thus causes the regulator to raise further until the maximum position is reached.

The regulator operation can be stabilized by reversing the reactance element of the line-drop compensator. With

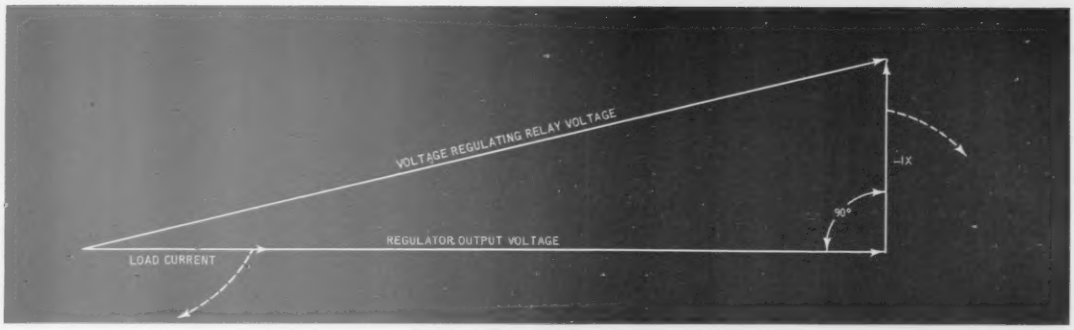


FIGURE 2

negative reactance compensation only, the regulator tends to maintain unity power factor. A vector diagram for the regulator control circuit with negative reactance at unity power factor is shown in Figure 2. Should the current *I* tend to lag the output voltage *V*, as represented by a clockwise rotation of the vector *I*, the negative reactance compensation vector *-IX* would also be rotated clockwise. This increases the voltage regulating relay voltage, causing it to unbalance and lower the tap position of the regulator until the reactive current decreases and unity power factor exists. Similarly, when the power factor tends to be leading, the vectors rotate counterclockwise and the regulator raises its tap position.

If the direction of power flow reverses from source *A* to *B* because of changes in local or generating conditions, the current vector of Figure 2 is rotated 180 degrees. This reversal also causes the negative reactance voltage drop vector (*-IX*) to rotate 180 degrees, giving a vector diagram identical with those for normal power flow, as shown in Figure 3. Thus the operation of the regulator is not affected by the direction of power flow through the regulator when it has two simultaneous sources but only by the amount of reactive current. Reverse power flow relays are not needed for this application.

The regulator does not receive true line-drop compensation with negative reactance compensation and tends to maintain practically the same output voltage at all loads. Since the negative reactance compensation is relatively small and in quadrature at unity power factor, it has very little effect on the control voltage. The effect is shown in the vector diagram in Figure 4. With a relay setting of 120 volts and 6 volts of negative reactance compensation, the output voltage is 119.9 volts. With twice as much load and the resulting 12 volts of negative reactance compensation, the output voltage is 119.8 volts, or practically unchanged.

It is sometimes desirable to have the regulator maintain a power factor other than unity. This can be done by using positive resistance compensation in addition to the negative reactance compensation. The ratio of positive resistance to negative reactance should be such that the voltage drop in the compensator circuit is in quadrature with the regulator output voltage, as shown in Figure 5. For a given power factor

$$\frac{\text{Negative reactance compensation}}{\text{Positive resistance compensation}} = \frac{\text{Power factor}}{\text{Wattless factor}}$$

The operation of the regulator is the same as when only negative reactance compensation is used, but the regulator maintains a power factor other than unity. When the power flow reverses, the vectors are again rotated 180 degrees, keeping the compensator voltage in quadrature with the control voltage.

The exact amount of negative reactance compensation to use in such cases is best determined by trial and error until stable operation is obtained. The regulator will not maintain an exact power factor but will operate over a small "Power Factor Band." The size of this band will depend upon the voltage regulating relay band, the amount of compensation used and the circuit constants.

It may be desirable to allow a certain amount of "base" reactive current to flow at all times and to limit the flow beyond this point. If constant reactive current is desired from source *A*, the voltage level of the regulator should

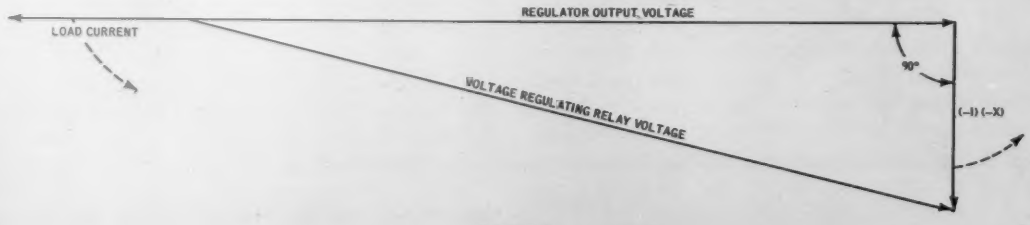


FIGURE 3

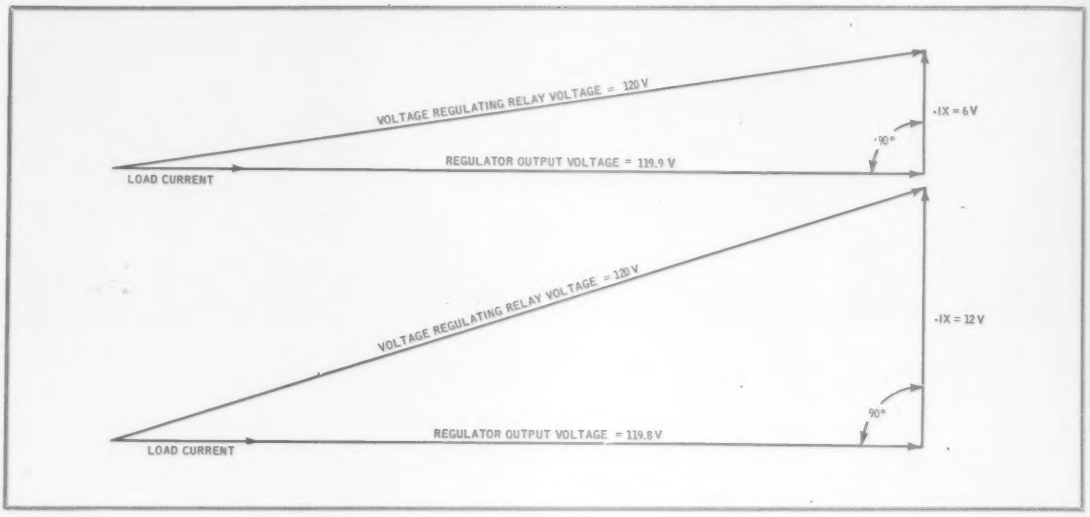

VOLTAGE REGULATING RELAY VOLTAGE = 120 V
-IX = 6 V
90°
REGULATOR OUTPUT VOLTAGE = 119.9 V
LOAD CURRENT
VOLTAGE REGULATING RELAY VOLTAGE = 120 V
-IX = 12 V
90°
REGULATOR OUTPUT VOLTAGE = 119.8 V
LOAD CURRENT

FIGURE 4

be raised until the proper amount of reactive current flows, while if constant reactive current is desired from source *B* the voltage level should be lowered correspondingly.

Simultaneous and switched power sources used

Both power sources in Figure 1 may be used simultaneously or at times one circuit may be switched off, as is the case when a small municipal or industrial generating system is connected to a large system. The small system may be shut down periodically for repairs or for lack of water in dry seasons. In such cases the regulator should be connected with its source or input side toward the constant power source, and reverse power flow equipment is not needed.

Where *either* power source is disconnected at times and both used at other times, reverse power flow equipment is necessary. In addition, for stable operation negative reactance compensation must be used to control reactive kva flow.

Reverse power flow equipment is necessary only when it is possible for power to be supplied by each source independently. Negative reactance compensation should be used to control voltage and reactive kva flow whenever it is possible for both power sources to be used simultaneously.

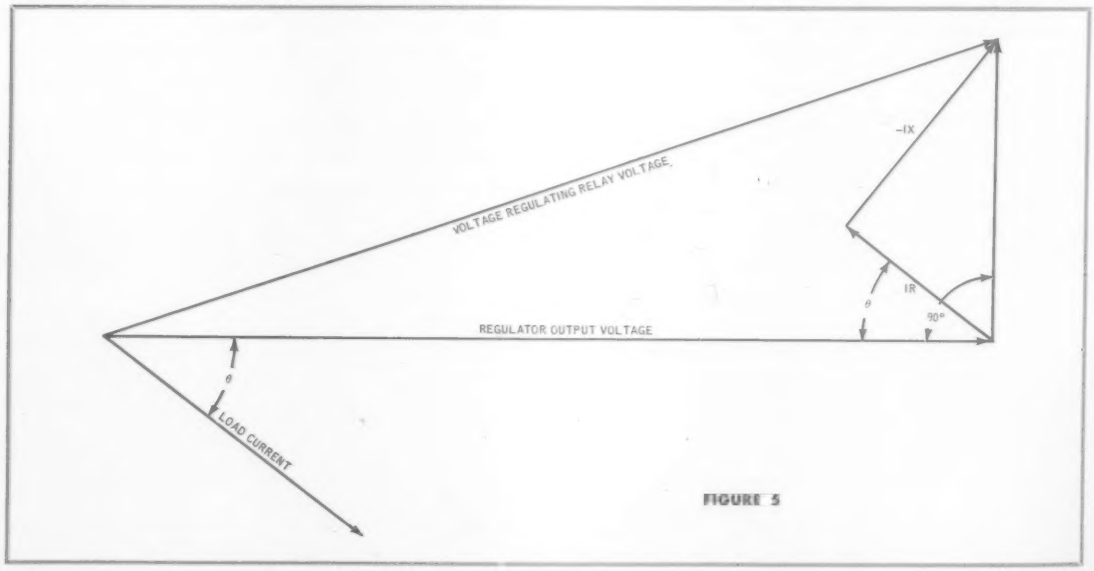
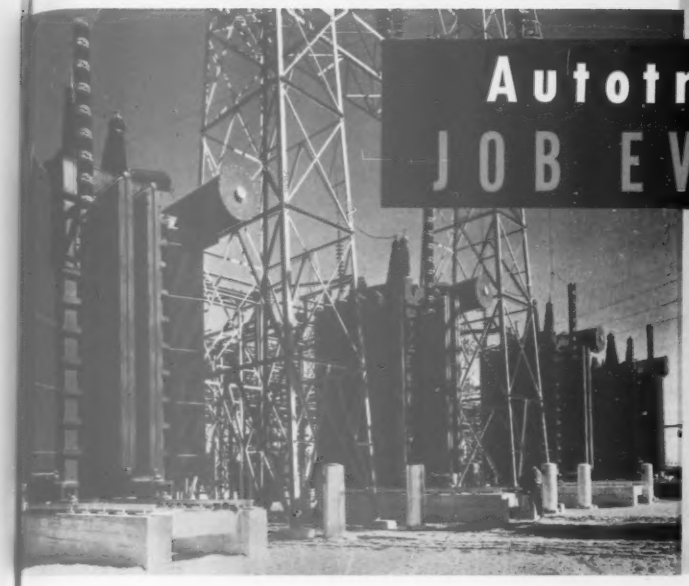


FIGURE 5

Autotransformer JOB EVALUATION



COST SAVING of 35 percent and weight saving of 29 percent were realized by using these 25,000-kva, 230-kv, 60-cycle, single-phase autotransformers rather than conventional transformers.

by **L. W. SCHOENIG**
Transformer Dept.
Allis-Chalmers Mfg. Co.

Considering the pros and cons of autotransformers for large power transformer jobs can pay big dividends.

MORE AND MORE autotransformers are finding their useful place on power systems principally because of their economies. These economies are evidenced in lower initial cost, lower losses, less weight, and smaller space requirements. The advantages of autotransformers over conventional two or three-winding units are many. However, there are a few disadvantages that should be carefully investigated before considering autotransformers for any particular job.

An explanation of the difference between two-winding and autotransformers may assist in obtaining a better understanding of autotransformers and their characteristics. The various circuits of a two or three-winding transformer are coupled only magnetically, whereas in an autotransformer the auto circuits are electrically connected. Diagrams for the two types of transformers are shown in Figures 1 and 2.

The two-winding transformer has a high voltage and low voltage winding wound on the same core. An autotransformer has one winding which is common to both high voltage and low voltage circuits, a winding which is in series with the high voltage circuits, and usually a tertiary winding. The tertiary winding is usually delta connected to provide a path for third harmonic magnetizing current. It is used to stabilize the neutral and protect the transformer under short circuits. To obtain sufficient thermal and mechanical strength under fault conditions the usual minimum capacity of a tertiary winding is 35 percent of the kva size of the larger of either the series or common windings. This capacity is based on actual kva size, not circuit ratings. The tertiary can also be used to supply loads, in which case its capacity must be designed in accordance with system needs.

Autotransformers are frequently used for loop circuits or interconnecting systems. This practical connection is a more efficient means of tying systems together than by doing so with two-winding transformers, because the ratio of the electrical size of the autotransformer to the electrical size of the two-winding transformer is equal to

$$\frac{HV - LV}{HV}.$$

The size of the autotransformer will therefore be considerably smaller than the comparable two-winding transformer. Usually, if the ratio of high to low voltage is not too great, the autotransformer will have lower impedance, lower exciting current, lower core and copper losses, and higher efficiency than the two-winding transformer. Lower impedance is a disadvantage under short circuit conditions, but usually there is sufficient impedance in the system to limit short circuit currents to a value of 25 times normal or less. All transformers, both auto and two-winding designed to meet ASA standards, will withstand short circuit stresses of at least 25 times normal for two seconds if the

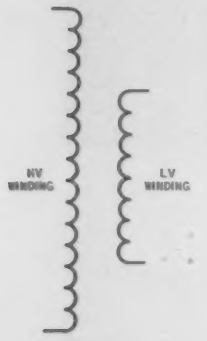


FIGURE 1

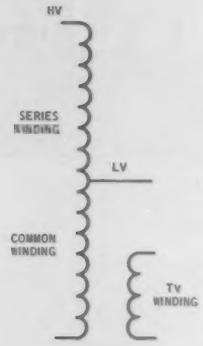


FIGURE 2

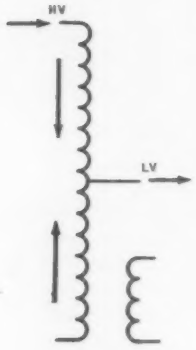


FIGURE 3

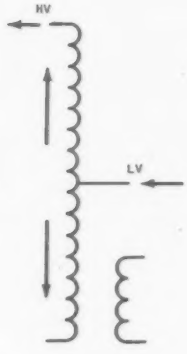


FIGURE 4

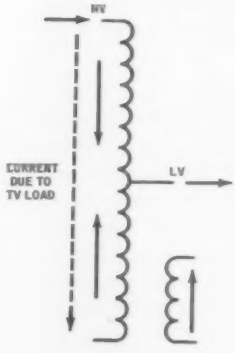


FIGURE 5

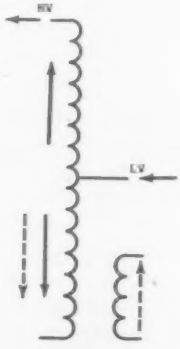


FIGURE 6

impedance is 4 percent or less. The lower impedance of the autotransformer has the advantage of contributing to better regulation.

Transformers compared

A comparison of the first cost as well as the electrical and mechanical characteristics of a conventional and an autotransformer, both rated 25,000 kva, self-cooled, three-phase, 138 kv Grd Y to 69 kv Grd Y, and the influence of a tertiary for harmonics are shown in Table I. The table shows the initial cost of the autotransformer to be about 65 percent of the conventional type. An even greater percentage savings is apparent when losses are considered. Autotransformer losses are only slightly more than half of those in the conventional unit. Impedance and regulation are also about half of that in the conventional transformer. In most cases weight and dimensions are not too important; however, the use of autotransformers will effect a reduction of about 30 percent. The weight advantage of autotransformers becomes a major consideration in very large kva units. It is possible to manufacture and ship autotransformers having much larger through kva capacity than conventional transformers.

The advantages of using autotransformers may be lost when the ratio of high to low voltage transformation exceeds 2 to 1. As this ratio increases, the electrical size of the autotransformer also increases. The initial cost, losses, impedance, weight, and dimensions being functions of electrical size also increase, reducing the spread between conventional and autotransformers.

Autotransformers can be economically applied to solidly grounded systems. It is possible, when the neutral is solidly grounded, to use reduced insulation, resulting in smaller, more efficient, lower initial cost transformers. If the neutral of the autotransformer is not solidly grounded, special attention must be given to the design of the common winding. It is the usual practice in this case to insulate the common or low voltage winding with the same class insulation as the high. If the neutral is grounded through an impedance or insulated for more than solid grounding (15-kv class), it is normally designed with the same insulation class as the low voltage line.

The principal advantages of using autotransformers can only be obtained with Y-connected units. Delta-connected autotransformers result in units having larger equivalent ratings, no neutral available for grounding or loading, and full insulation on both series and common windings. For these reasons, delta-connected autotransformers are not commonly used on high voltage power systems.

To insure safe and stable operation, three major items must be considered when evaluating a job for possible application of autotransformers:

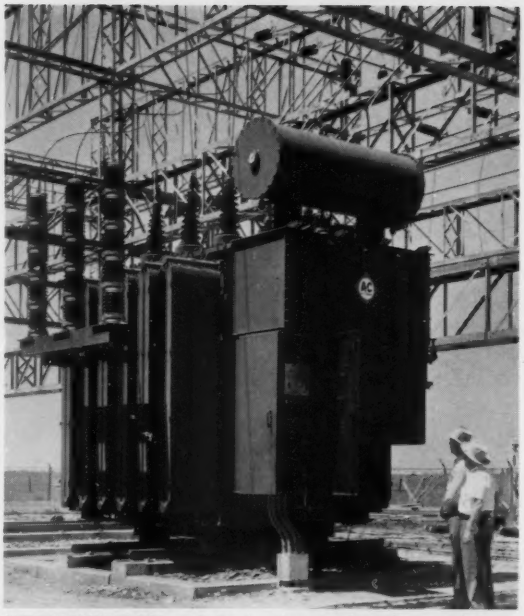
1. Grounds on power systems and their effect on line-to-neutral voltage.
2. Third harmonic problems and their effect on stability and interference.
3. Switching and impulse surges and their effect on insulation.

The voltage stresses resulting from grounds on power systems can be limited to safe values by grounding the neutral of the autotransformer. The third harmonic problems can best be solved by including a delta-connected tertiary in the autotransformer. The delta winding provides a path for third harmonic currents, thereby eliminating telephone interferences. The delta winding also stabilizes the neutral during fault conditions by providing a path in the transformer for fault currents. The capacity of the delta tertiary need be only 2 or 3 percent of the autotransformer capacity to handle the third harmonic currents. However, to stabilize the neutral and protect itself under fault conditions, the rating of the tertiary must be 35 percent of the transformer rating. Transient voltages resulting from switching or impulse can best be limited to safe values by properly applied lightning arresters.

Autotransformers, like multi-winding units, can be operated step up or step down. The current distribution is shown in Figure 3 for step-down operation and Figure 4 for step-up operation. When a load is taken from the tertiary, the high-to-low capacity depends on the tertiary load and the type of operation (step down or step up). The current distribution for step-down and step-up operation is shown in Figures 5 and 6, respectively.

Figure 5 shows how the component of current in the series winding resulting from the tertiary load adds to the component of current resulting from the high-to-low voltage load. In the common winding, however, the two components subtract from each other. When operated step up, as shown in Figure 6, the component of current due to the tertiary load flows only in the common winding and adds to the component of current resulting from the high-to-low voltage load. It should be remembered that the components of current are vector quantities and must be added vectorially.

In view of the current distribution in autotransformers, it is very important that autotransformer specifications be written to include all loading conditions, since they influence transformer design. If the tertiary of an existing autotransformer is to be loaded, it is important to check the capacities of the series and common windings, as these may limit the transformer loading.



AUTOTRANSFORMER with load ratio control used as tie between a southern utility system's 69-kv and 34½-kv voltages is rated 30,000 kva, three-phase, 60 cycles and is well suited to the job.

As time goes on, more and more autotransformers will be applied to power systems. It is important, therefore, to understand fully the advantages and disadvantages of this type of equipment. A thorough understanding can result in more transformer capacity per dollar, more efficient transformer usage, and transformer reliability equivalent to conventional units.

TABLE I

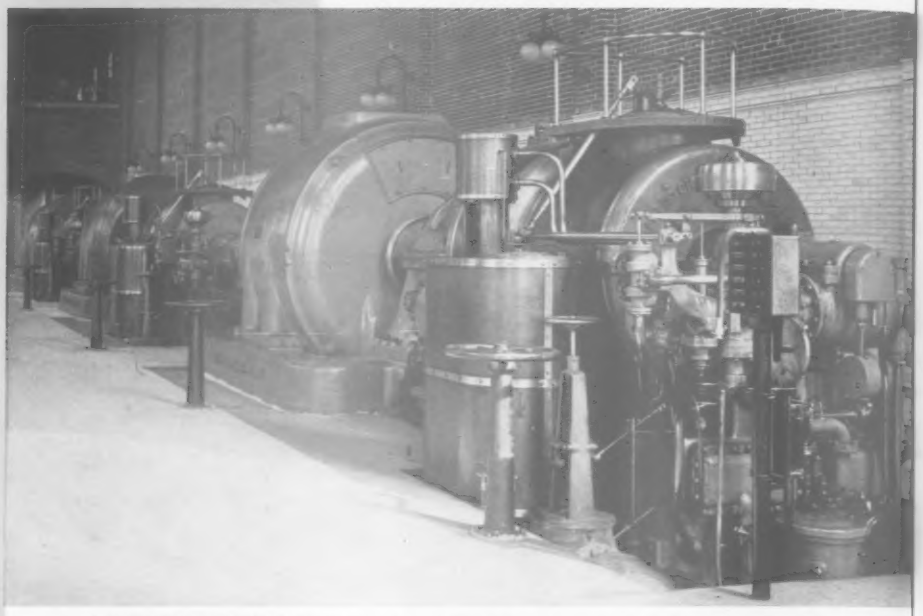
	AUTOTRANSFORMER		CONVENTIONAL TRANSFORMER	
	NO TERTIARY	WITH TERTIARY	NO TERTIARY	WITH TERTIARY
Initial Cost (dollars)	94,500	102,000	145,000	156,000
Winding Rating (kva)	13,128	15,540	25,000	29,375
Core Loss (kw)	40	48	50	60
Total Loss (kw)	108	116	200	210
Impedance HV to LV (%)	6	6	11	11
Regulation HV to LV at 0.8 pf (%)	4.0	4.0	7.5	7.5
Total Weight (lb)	145,000	155,000	205,000	220,000
Floor Space (inches)	180 x 170	190 x 170	200 x 180	210 x 180

METAL CREEP at high temperatures is being measured with a micrometer microscope by a Research Laboratory engineer sighting through the window of a cylindrical furnace. Metal samples within the furnaces, stressed with levers and dead weights, are held at dull red heat for months. Stresses and temperatures are precisely controlled so that information essential to the design of steam or gas turbines for higher temperature operation can be gathered.

A-C Staff Photo by M. Durante

Steam Turbine HISTORY HIGHLIGHTS

PART III



FIRST STEAM TURBINE STATION of Metropolitan Edison Company at West Reading, Pennsylvania, now Eyler Station, is shown in this 1910 picture. Two of these Allis-Chalmers 4500-kw, 1800-rpm units, among the largest of their day, are still in operation for stand-by service on the system.

by R. C. ALLEN
Consulting Engineer
Allis-Chalmers Mfg. Co.

This, the concluding article of a series, discusses significant recent developments.

PROGRESS IN STEAM TURBINE construction has seen the engine efficiency increase from less than 60 percent in 1900 up to the middle 80's at the present time. This improvement is all the more spectacular when it is remembered that the heat drop in a modern turbine may be over twice that of the turbines of 1900, and that leakage as well as windage losses are greater because of the higher pressures now employed.

The past half century has seen a rigorous attack on the principles of fluid flow with respect to the most efficient forms of nozzle and blade passages. This problem has been developed in theory as well as by countless experiments during which turbine components and complete machines have been thoroughly tested. Approximately 30 years ago, and as the result of aircraft development, attention was directed toward the application of the circulation theory to steam turbine blade forms. Various modifications of this theory have been applied to large turbine blade design and as now employed are effective in accomplishing radial stability of the elastic fluid. Component testing has indicated that a substantial improvement may be realized in long blades by designing them on this basis, although the blade form becomes quite complex.

The principle of bypass control introduced before 1900 permitted a full admission reaction turbine to operate with full inlet pressure at some selected partial load. This arrangement made possible a substantially better light load efficiency than could be realized if the blade path were designed to carry full load with one admission point.

A most outstanding development was the practical application of interstage steam extraction for the heating of boiler feedwater. The advantage of this process in cycle improvement was pointed out by Professor Elliott in 1884. One of the first installations on record using this principle was in connection with a reciprocating engine pumping plant in the United States in about 1900. Karl Baumann, of the Metropolitan Vickers Company, accomplished a great deal toward bringing to public attention the cycle improvements which can be realized by interstage extraction for feedwater heating. It is current practice to employ six or more stages of extraction in large central stations.

It was early recognized that the introduction of reheat in the steam path would improve the heat rate and result in drier steam in the last stages of the turbine, and thus reduce erosion of high tip speed blades. One of the first applications of reheat was at the North Tees plant in England. An early 65,000-kw reheat unit installed at Waukegan, Illinois, is shown in Figure 1. Another notable application was made in 1935 at the Port Washington plant of the Wisconsin Electric Power Company which directed particular attention to the advantages of reheat in central station practice. This 80,000-kw unit is shown in Figure 2. The trend of recent years is toward the increased application of reheat.

Steam conditions improved

Developments in boiler construction, turbine design, and station layout have made possible the gradual increase in steam pressures up to 2400 psi. The most commonly accepted initial steam pressure at the present date appears to be approximately 1800 psi for central stations.

There has been a parallel progress in steam temperatures which have increased from around 400 F in 1900 to a presently accepted level of 1100 F. Present temperatures are made possible by outstanding advances in metallurgy and by the solving of the many complex engineering problems associated with the thermal expansion of the various machinery components.

The peak in the march of progress in this field appears to be contained in the recent announcement by Philip Sporn, president of the American Gas & Electric Company, that a new unit is to be installed in the Philo plant in which the initial pressure will be 4500 psi and the temperature 1150 F. This courageous step well illustrates the ever-changing pattern of development confronting power machinery engineers.

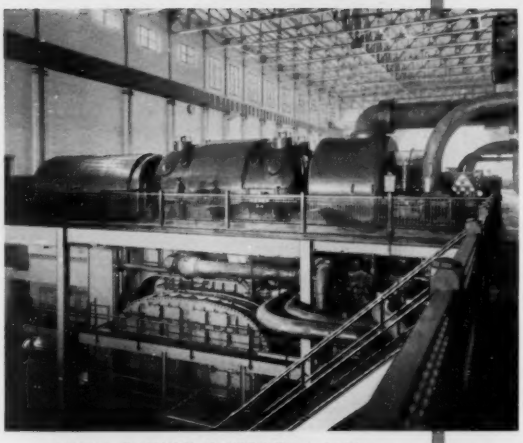
The operating characteristics of the condensing equipment have been improved by good design to provide exhaust vacuum levels that are presently established at from 28.5 to 29 inches of mercury referred to a standard barometer. A few large installations are now equipped with turbines and condensing systems designed for an exhaust pressure corresponding to 29.5 inches of mercury. The last three Port Washington units have exhaust ends designed to take advantage of 29.5 inches mercury vacuum. Going back 50 years, many of the turbines of that era were designed for a vacuum in the exhaust of 26 to 27 inches.

Turbine design advances

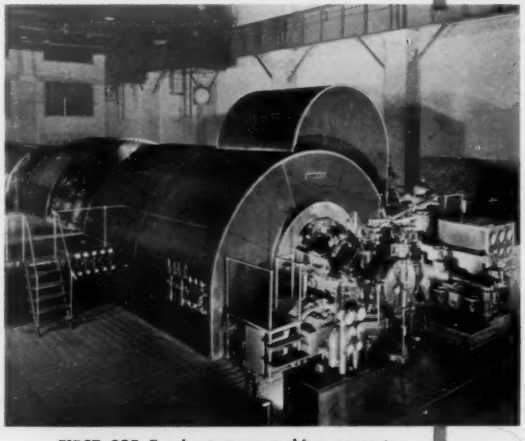
There are sound economic reasons that favor the employment of the highest possible rotative speeds for large turbine generating units. A limit design of turbine at 1800 rpm will weigh twice as much per kilowatt of rating as a geometrically similar 3600-rpm machine. The higher speed machines can be expected to be cheaper to build per kilowatt of rating and they can be produced with smaller machine tools.

The 1500-kw Hartford turbine of 1900 ran at 1200 rpm. The trend of present design practice points toward the construction of 3600-rpm single generator units for ratings up to more than 300,000 kw.

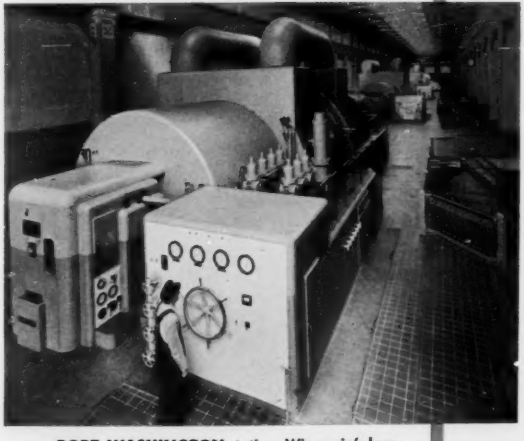
The past 50 years have included great advances in the support of turbine casings directed at means for maintaining the axes of the moving and stationary elements coincident under varying loads and temperatures. The basic principle is the use of close to centerline support, arranged to permit free transverse expansion. Vertical keys locate the structure transversely without restricting vertical expansion. Figure 4 shows such a plan of supports. Internal elements in high pressure casings, such as reaction blade rings or impulse turbine diaphragms, have been arranged to permit their free expansion.



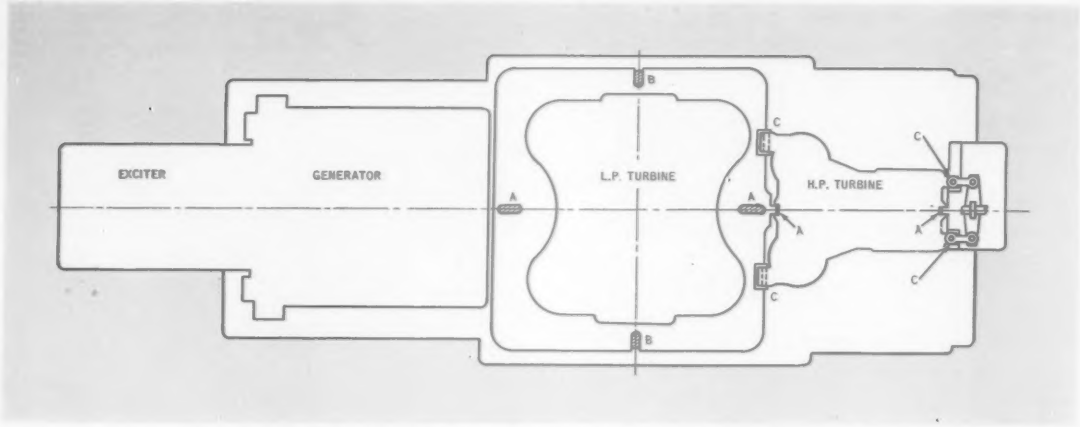
EARLY TANDEM-COMPOUND 1800-rpm, 65,000-kw reheat turbine at Waukegan was placed in service in May 1930. **(FIGURE 1)**



FIRST 825 F reheat steam turbine generator unit, installed in 1935, became the key part of world's most efficient power station. **(FIGURE 2)**



PORT WASHINGTON station, Wisconsin's largest, has five 80,000-kw reheat units operating at 29½ inches average vacuum. **(FIGURE 3)**



KEYS AND SUPPORTS used with modern steam turbines provide transverse location at *A*, axial anchorage at *B*, and centerline support at *C*. **(FIGURE 4)**

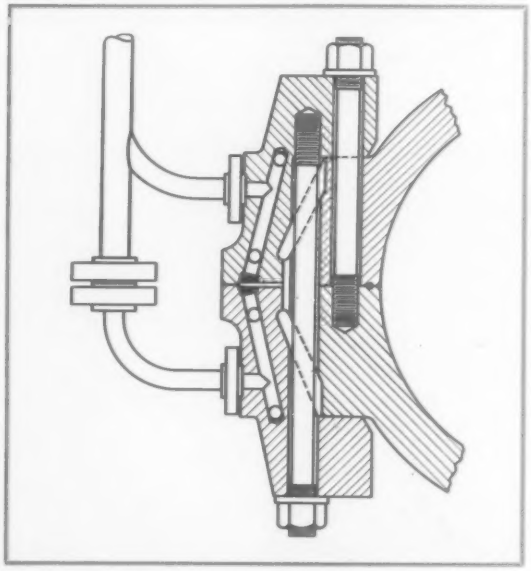
The development of main high pressure casings has largely centered around the study of bolted joints. The increased bolt power made possible with the clamped flange construction of Hans P. Dahlstrand was successfully applied to many high temperature turbines, as shown in Figure 5. Casing flange designs have reached proportions in which bolts of six inches in diameter are used.

Great changes have taken place in blade design. Blading systems have been developed which will withstand high and variable temperatures, high centrifugal and bending stress, and avoid resonant vibration. These objectives have been accomplished with due regard for manufacturing costs.

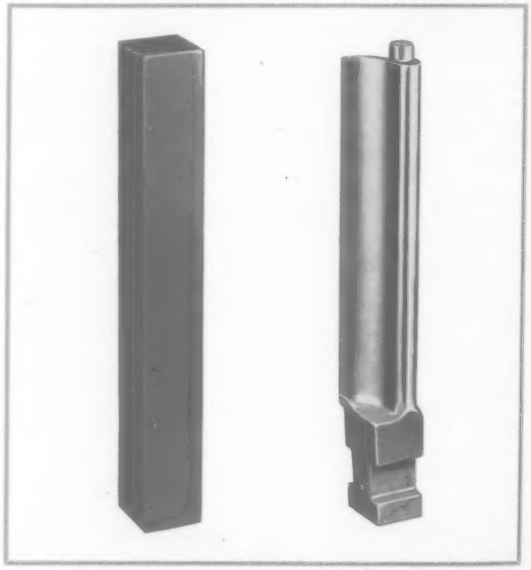
The erosion of low pressure blades as the result of entrained moisture has received much attention. Means have been provided for separating moisture from the blade path and for the application of erosion-resisting shields to the blade inlet edges.

Design trends have led to the adoption of blades, for the major portion of the steam path, which are formed with integral roots or base portions. This type blade is shown in Figure 6.

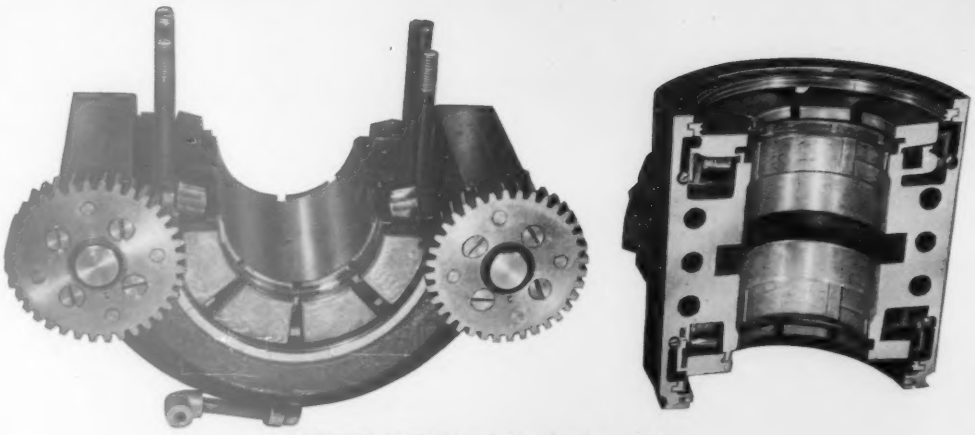
Blading materials have passed through many phases of experimental development and use. Starting in the early 1920's, 13 percent chrome stainless steel became the standard steam turbine blade material. In recent years modifications have been made to this alloy to improve its physical properties.



HANS P. DAHLSTRAND is credited with this high strength, high temperature clamp-type bolted joint. **(FIGURE 5)**



THE MAJORITY OF MODERN BLADES are machined from heat-treated 13-chrome steel bar stock. **(FIGURE 6)**



COMBINED JOURNAL and thrust bearing — showing the Kingsbury tilting-pad elements. **(FIGURE 7)**

Materials have undergone extensive developments with particular regard to properties at high temperature. The terms "stress rupture" and "creep" have come into everyday use. Metallurgical science deserves great credit for the work which has been accomplished in the development of reliable materials for blading, spindles, and casings.

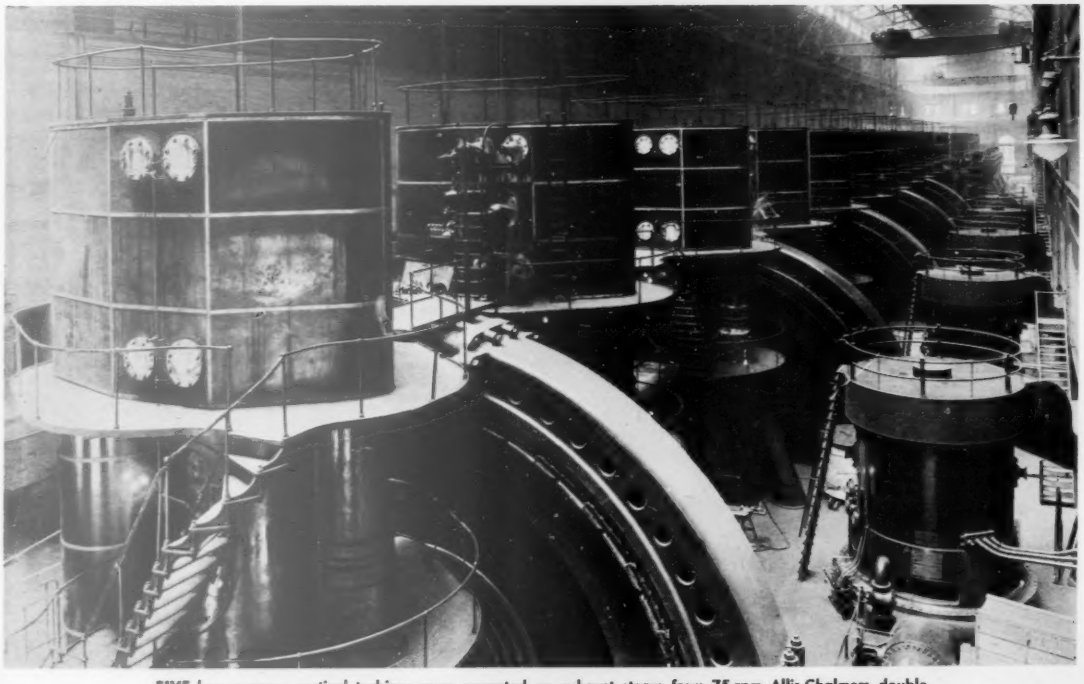
The techniques involved in the production of large spindle and disk elements include advanced procedures for producing forged steel components in which the metallurgical and geometrical axes are as closely as possible coincident. Advanced scientific inspection aids, such as the high power X-ray and ultrasonic tests, are now applied to determine soundness of the parts.

Figure 7 shows the tilting-pad thrust bearing developed by Kingsbury in the United States and Michel in Europe. The greater reliability and higher load-taking capacity of this bearing resulted in its early adoption by most large steam turbine builders.

Main governors are now designed to respond to extremely small speed changes in the interest of system load control.

One turbine builder in this country employed an air impeller as the speed responsive element. One manufacturer has developed and standardized on a centrifugal oil governor in which the variation in oil pressure at the discharge of a rotating impeller is employed as the regulating means.

The introduction of the unbalanced plug type control valve aided materially in solving valve leakage problems associated with the double-seated valves of the earlier units.



FIVE low pressure vertical turbines were operated on exhaust steam from 75-rpm Allis-Chalmers double angle compound engines, 42 and 86 x 60 inches, 200 psig. Four units are still in operation. **(FIG. 8)**

THERMAL PERFORMANCE OF STEAM POWER PLANTS OF HISTORICAL INTEREST

Expressed As Net Plant Heat Rate on the Equivalent Basis of Btu Per Kwhr

PLANT	YEAR	UNIT SIZE (KW)	EQUIVALENT HEAT RATE (BTU PER KWHR)
Savory steam engine plant	1699	——	2,000,000
Newcomen steam engine plant	1760	——	500,000 to 600,000
Watt steam engine plant	1780	——	150,000 to 200,000
Edison Pearl Street plant	1882	55	150,000
First steam turbine plant	1900	1,500	50,000
74th Street I.R.T. engine plant	1903	7,500	40,000
Good steam turbine plant, World War I	1918	30,000	20,000
Good steam turbine plant, post World War I	1925	40,000	15,000
Good steam turbine plant, World War II	1945	100,000	11,000
Best steam turbine plant, post World War II	1952	200,000	9,000
Theoretical limit set by the Carnot Cycle with 2500 F combustion temperature	Then Now Future	——	4,100
Theoretical limit set by the Carnot Cycle with nuclear fission temperature of 10^6 F	Then Now Future	——	3,413

Courtesy of *Combustion* Magazine

The plug valve requires a powerful control mechanism which, in spite of its massiveness, is made to regulate valve positions with great precision.

The requirement of utilities that large turbines shall not trip their overspeed governors when the generator load is lost in one step has made further refinements necessary in the direction of extremely fast control mechanisms.

The potential overspeed capacity of the steam trapped in reheat boiler systems requires intercepting and dump or stop valves, which impose still further duties on the governor control mechanisms.

Even in 1900, the Elberfeld turbines were of tandem construction. Multiple cylinder practice continues to be applied to large machines, and it is presently concluded that future turbines must employ this principle for outputs beyond the limit of a single low pressure blade annulus. This practice involves the use of two or more turbines connected to a single generator as well as to the alternate cross-compound arrangement. The principal advantage of the cross-compound arrangement is that the high and low pressure turbines may be operated at different synchronous speeds. In one of the earliest applications of the cross-compound idea, some 40 years ago, the low pressure element operated at a speed of only 750 rpm.

There has been a continued interest in large single-cylinder construction for condensing machines. The present 3600-rpm, 30,000-kw, single-flow unit is standard equipment. From present indications, still larger 3600-rpm central station units will be built.

Industrial turbines economical

Many turbines have been built to serve special industrial requirements. Numerous condensing and non-condensing machines were placed in service in paper mills, plants producing food products, etc.

An important type of industrial unit is the automatic "bleeder," which may operate either condensing or non-condensing but which is designed with automatic extraction control at one or more interstage points. Frequency control is maintained under conditions of variable electrical and extraction loads.

Steam turbines dominate marine field

Part I of this article indicated some of the early installations in the marine propulsion turbine field. The last 50 years have witnessed the application of the steam turbine as the usual prime mover for the propulsion of passenger and cargo vessels and warships. After a long and hard battle with electric drive plants, the geared steam turbine has emerged as the preferred type of propulsion unit.

Large low pressure turbines find use

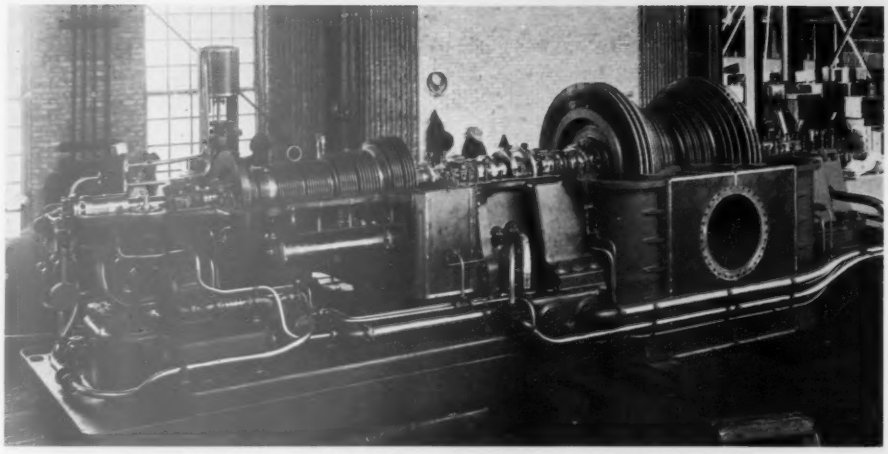
During the years shortly after 1900 a number of notable low pressure turbine installations wherein the turbines received their steam from reciprocating engines were placed in service. A noteworthy instance is the installation in 1908 of 7500-kw, 750-rpm vertical General Electric low pressure turbines in the 59th Street Station of the Interborough Rapid Transit Company in New York, now the New York City Transit Authority. It was learned only recently that four of these turbines are still in operation. The Allis-Chalmers engines, installed in 1901, that exhaust to these turbines drive 7500-kw, 40-pole generators. Figure 8 shows a general view of this installation.

Another interesting application of 40 years ago is a mixed pressure unit at the stamp mill of Calumet and Hecla, Inc., at Lake Linden, Michigan. Figure 9 shows a

BUILDING VOLUME AND FLOOR SPACE REQUIREMENTS OF REPRESENTATIVE STEAM ELECTRIC OPERATING PLANTS 1900–1950

PLANT	YEAR	PLANT SIZE (KW)	BUILDING VOLUME (CU FT PER KW)	FLOOR SPACE (SQ FT PER KW)
74th Street I.R.T. reciprocating engine plant	1903	45,000	180	2.0
Good steam turbine plant, World War I	1918	100,000	40	0.35
Good steam turbine plant, post World War I	1925	150,000	35	0.25
Good steam turbine plant, World War II	1945	200,000	30	0.22
Good steam turbine plant, post World War II	1950	300,000	25	0.20

Courtesy of *Combustion* Magazine



LARGEST MIXED PRESSURE TURBINES, 1913 and 1918, rated 7500 and 10,000 kw, 1500 rpm, built for Lake Linden, Michigan, mills of Calumet and Hecla, Inc., used 12-inch exhaust blades on 54-inch drum diameter. These units are in service today. **(FIG. 9)**

view of this 7500-kw Allis-Chalmers tandem turbine. The low pressure element was designed to operate with steam at 1.8 psig, using exhaust steam from the stamp mills.

The superimposed or "top turbine"

Hans P. Dahlstrand pointed out in 1925 that, as a result of advanced boiler design which made available higher operating steam pressures, the superimposed or "top turbine" could be installed in many existing central stations to increase the generating capacity and to improve overall economy.

Following 1929, there was a period during which steam pressures of 1200 psi and temperatures exceeding 750 F became accepted practice. During this time a considerable number of high initial pressure, high back pressure turbines were installed to exhaust into the existing steam turbine plants where the steam inlet pressures were of the order of 250 psi. Increased capacity was made possible with improvements in plant efficiency. An outstanding top turbine is shown in Figure 10.

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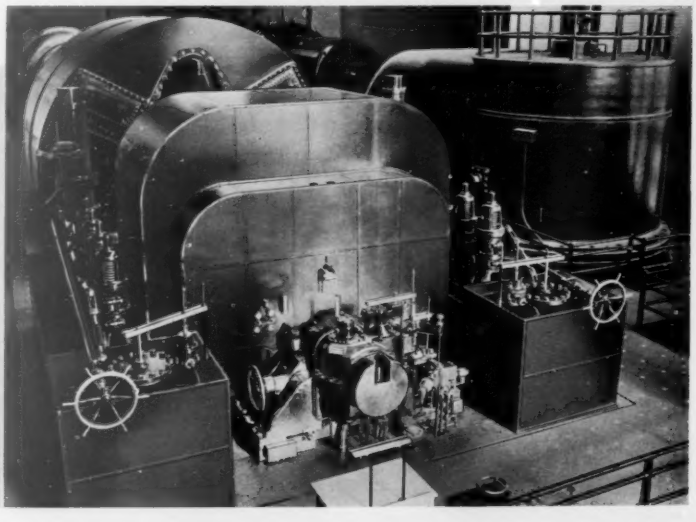
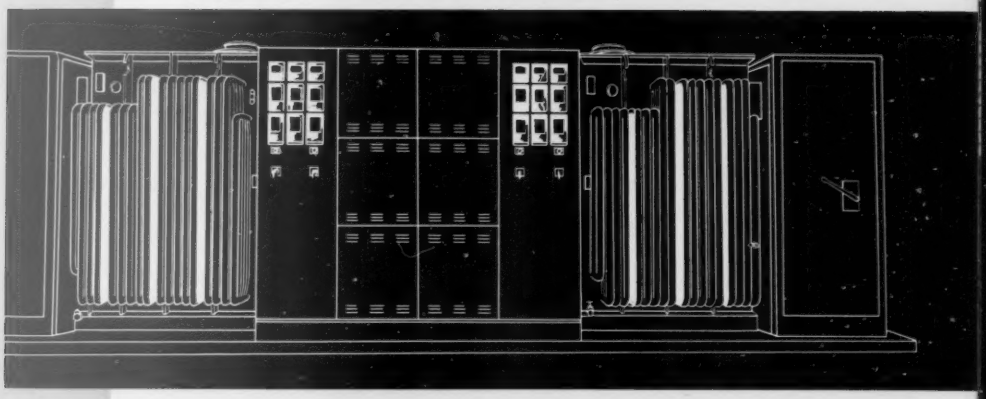


50,000-KW TOP TURBINE, built in 1942 for Northwest Station of Commonwealth Edison, Chicago, was the culmination of development on heavily loaded partial admission impulse blades. Inertia governor minimizes jump in speed if high load is lost in one step. **(FIGURE 10)**

PRODUCING ONE POUND OF ALUMINUM from alumina requires ten kilowatthours of electric power. These twenty-four 6000-ampere, 750-volt *Excitron* rectifier assemblies — with a total capacity of 108,000 kw — supply two aluminum pot lines at ALCOA's Wenatchee Aluminum Reduction Plant. Reduction occurs within aluminum pots by passing direct current through an electrolyte of alumina (aluminum oxide) dissolved in molten cryolite. Pure aluminum settles to the bottom of each pot and is removed periodically.



When Specifying Double-Ended Unit Substations

CONSIDER THE DUO-DUPLEX

by **WARREN BIRGEL*** and **JOHN A. KEYMAR**
Switchgear Department
Allis-Chalmers Mfg. Co.

Here's an industrial unit substation for a four feeder arrangement that combines maximum reliability with economy.

WHEN AN INDUSTRIAL PLANT requires a highly reliable power supply, double-ended unit substations are usually specified. While reliability is increased somewhat by adding the second transformer, still further operating advantages as well as greater economy may result if due consideration is given to the arrangement of breakers within the low voltage switchgear.

The nature of a unit substation is determined by the type of transformer and switchgear units involved, together with the number and arrangement of each. However, no standards have been published for secondary substations. Consequently, specific nomenclature has not been established, and the names given to similar primary substations are usually applied.

For example, one type primary substation is known as the duplex. It is a double-ended unit substation employing two load ratio control power transformers, two combination transformer secondary and feeder breakers, and one tie breaker for only two feeder circuits. See Figure 1. The power transformers are never paralleled and each normally carries the load of one feeder.

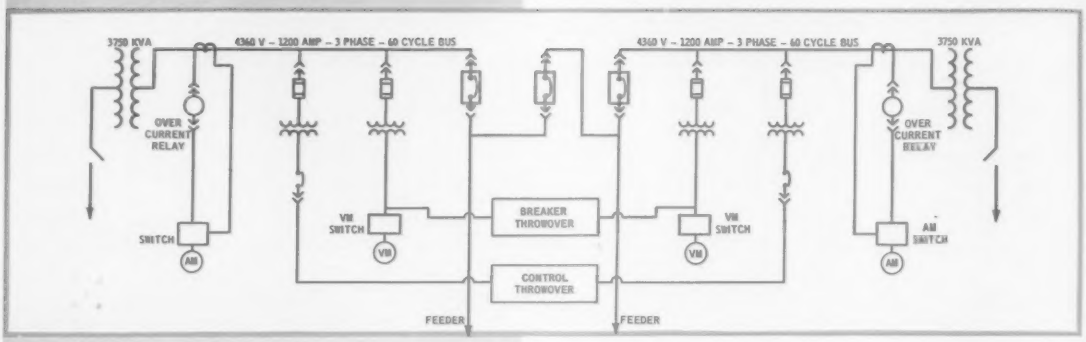
In addition to the usual protective relaying operations, automatic throwover equipment will transfer the load of either transformer to the other in the event of a power failure due to loss of primary voltage or a transformer failure. This type of unit substation is extensively used on utility power systems where good regulation and continuity of service are prime considerations. The cost per kilowatt of load is quite high because each transformer is large enough to carry the entire substation load independently and elaborate relaying schemes are incorporated.

Industrial counterpart is simpler

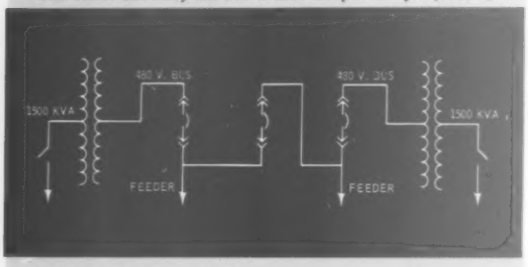
Similarly, the double-ended industrial substation having two combination transformer secondary and feeder breakers and one tie breaker for only two feeder circuits is called a duplex substation. See Figure 2.

The cost per kilowatt of load is held to a minimum commensurate with good engineering practices by eliminating transformer load ratio control equipment. Regulation is accomplished on the primary voltage by the power company. Automatic throwover equipment is usually eliminated because the benefits obtained from a throwover scheme do not justify the additional expense on an industrial electrical system where most of the load consists of motors. Further economy can be realized by using either

* At the time this article was written, Mr. Birgel was an application engineer in the Switchgear Department.



PRIMARY DUPLEX substations are double-ended with automatic throwover equipment and transformers large enough so that either can carry the entire load independently. **(FIG. 1)**



ESSENTIALLY THE SAME as its primary counterpart, the industrial duplex unit substation is usually simplified by eliminating automatic equipment. **(FIGURE 2)**

BREAKING RATINGS IN AMPERES		METHOD OF OPERATION
Interrupting	Continuous	
100,000	6000	Electrical
100,000	5000	Electrical
100,000	4000	Electrical
75,000	3000	Electrical
75,000	2000	Electrical
50,000	200 to 1600	Electrical
50,000	200 to 1600	Manual
25,000	50 to 600	Electrical
25,000	50 to 600	Manual
15,000	25 to 225	Electrical
15,000	25 to 225	Manual

FIGURE 3

transformer secondary breaker element as a tie breaker when it becomes necessary to feed both loads from one transformer.

Load center substations employ low voltage metal-enclosed switchgear with air circuit breakers in the various ratings shown in Figure 3. These air circuit breakers each have two current ratings: continuous and interrupting capacity. Those rated 50,000 amperes interrupting capacity and below can be either manually or electrically operated, while all above this rating are electrically operated only. Both current ratings must be taken into consideration for any particular application.

Some of the most common transformer ratings utilized in duplex load center unit substations are 750, 1000, and 1500 kva with a 480-volt secondary, either delta or wye connected. Available maximum fault currents and secondary full-load currents of these transformers at 480 volts with standard 5.5 percent impedances and 250-mva primary fault capacities are shown in Figure 4.

Both current ratings considered

A comparison of the circuit breaker current ratings, Figure 3, with the transformers requirements, Figure 4, shows that the 25,000 and 50,000-ampere breakers have adequate interrupting capacity as feeder breakers for the 750 and 1500-kva transformers, respectively, but do not have the proper continuous current ratings for use as transformer secondary breakers. This would seem to indicate that the two current ratings of these low voltage air circuit breakers are not entirely compatible when used in duplex load center unit substations of the ratings under consideration. However, the breakers with lower continuous current ratings can be utilized if they are applied in the form of a duo-duplex unit substation. Figure 5 shows a single-line diagram of this substation arrangement.

Duo-duplex substation has operating advantages

This arrangement employs two combination transformer secondary and feeder breakers for each transformer and two tie positions connecting them together. The result is a substation with four independent feeder circuits, each fed by a breaker smaller than that required for a similar duplex unit substation. Typical industrial duplex and duo-duplex unit substations are shown in Figures 6 and 7.

KVA RATING	FULL-LOAD CURRENT	MAXIMUM AMPERE FAULT CAPACITY AT 480 VOLTS 250,000-KVA INCOMING SOURCE
750	902	24,000
1000	1203	31,500
1500	1804	46,000

FIGURE 4

Several advantages are realized with the duo-duplex unit substation:

1. A fault on any one of the four feeder circuits will result in the loss of only one quarter of the substation load rather than one-half, as with a normal duplex.
2. Substation operation is more flexible. Part of one transformer's load can be shifted to the other when necessary, and a full shift can be accomplished more easily because the circuit breakers are smaller.
3. Greater load protection can be realized because the smaller loads involved require lower trip coil settings.

The duo-duplex substation utilizing 1500-kva transformers has several very important additional advantages even more desirable than those stated above.

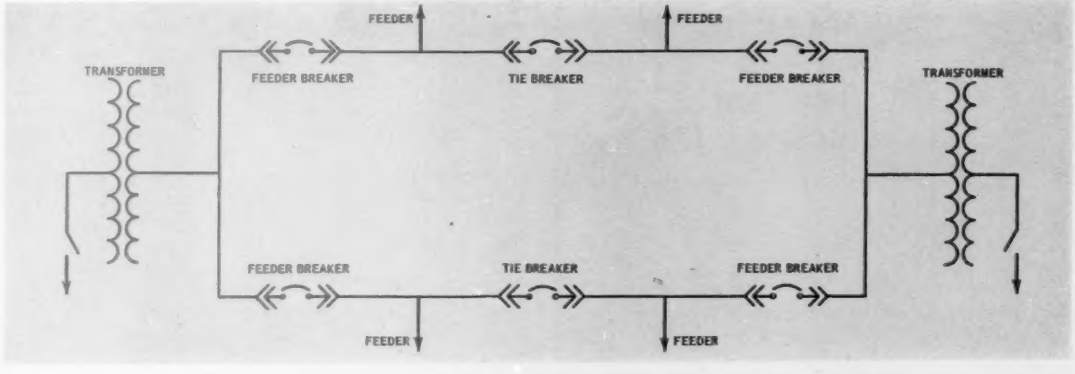
Full-load current of these transformers is 1804 amperes. In a normal duplex unit substation, a 2000-ampere continuous, 75,000-ampere interrupting capacity electrically operated circuit breaker would be required. However, present-day transformer design makes allowances for rather large short-time overloads which, in this case, could easily exceed 2000 amperes. Since a low voltage air circuit breaker has no overload rating, a 3000-ampere breaker would be required in order to take advantage of the transformer's overload capacity. This is also true of any substation with transformers having forced-air cooling or provision for future forced-air cooling.

THREE BREAKERS between two transformers identify this as an industrial duplex unit substation. All three manually operated breakers are rated 50,000 AIC. **(FIG. 6)**

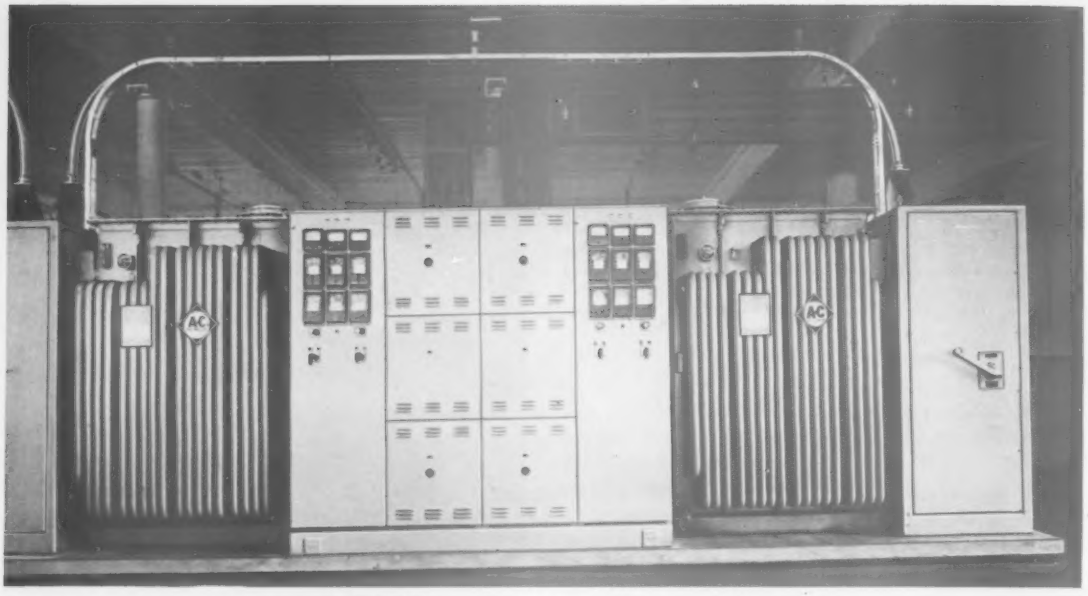
In a duo-duplex unit substation having two 50,000-ampere interrupting capacity, 1600-ampere continuous rating air circuit breakers for each transformer, a total load of 3200 amperes could be drawn without exceeding the thermal capacity of the air circuit breakers.

Duo-duplex can be more economical

The cost of two electrically operated 50,000-ampere breakers is less than that of one 75,000-ampere (2000-ampere continuous) air circuit breaker which can only be supplied electrically operated. If manually operated 50,000-ampere breakers are specified instead, the saving in cost of original equipment would exceed 25 percent. If a 3000-ampere



THE DUO-DUPLEX substation differs from the industrial duplex in that it has four independent feeder circuits. In effect, two duplex breaker arrangements are paralleled. **(FIGURE 5)**

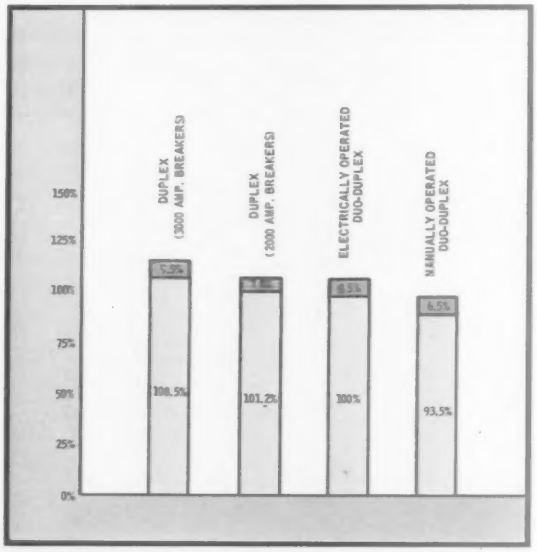


SIX BREAKER compartments indicate that this is a duo-duplex substation. Four electrically operated 50,000 AIC feeder breakers are separated by tie breaker compartments. **(FIG. 7)**

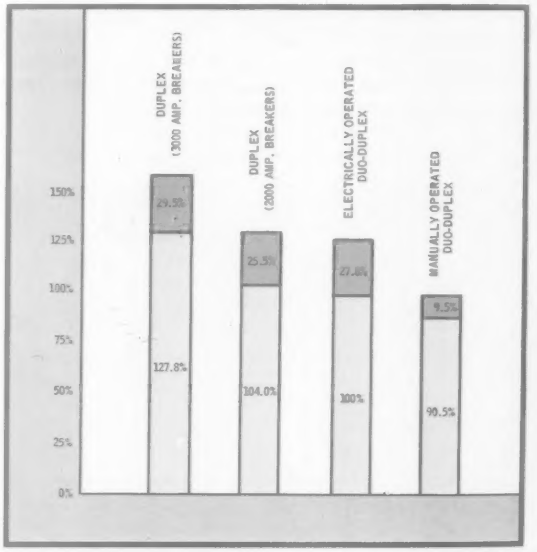
continuous rating, 75,000-ampere interrupting capacity breaker is required, the difference is still greater. This saving is illustrated in the bar graphs of Figures 8 and 9, which show the percentage increase of a duplex over a duo-duplex of the same kva rating.

The duo-duplex unit substation with 750-kva transformers is slightly more expensive than a normal duplex. However, in this case, the numerous operational advantages of the duo-duplex should be weighed against the small additional cost.

Regardless of its rating, when a secondary duplex unit substation is contemplated, both operating and economic advantages of duo-duplex unit substations should be considered before arriving at a final decision.



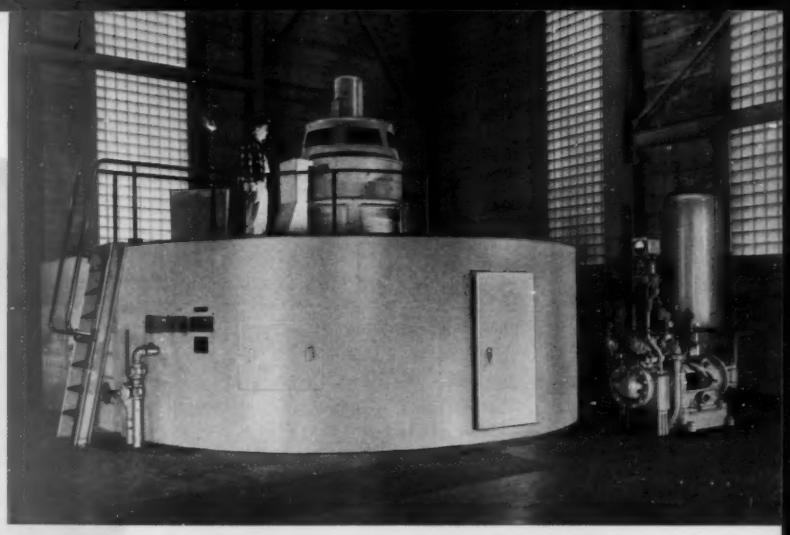
COMPARATIVE COSTS of 3000-kva duplex and duo-duplex LCS industrial substations are indicated by these bar graphs. Darker areas at the top of each bar indicate the tie breaker removable elements, lighter areas, the other switchgear elements and transformers. **(FIG. 8)**



WHEN ONLY THE SWITCHGEAR is considered, the duo-duplex arrangement is even more economically desirable for a 3000-kva substation — it affords utilization of transformer overload capacity comparable to the duplex unit with 3000-ampere breakers. **(FIG. 9)**

NEW VIBRATION WARNING DEVICE

For Hydro Turbine Generators



INSTALLED on this unit at a remotely supervised station four years ago, a pilot model deflection indicator is giving completely satisfactory service. **(FIGURE 1)**

by **H. H. ROTH and B. R. OLSON**
Motor and Generator Section
Allis-Chalmers Mfg. Co.

RELIABLE SERVICE OF HYDRO POWER stations depends to a large extent upon adequate warning and protective devices.* Only recently, however, has remote indication of vibration in a hydraulic turbine-generator shaft become possible. Early detection of excessive vibration may permit correction of some abnormal condition within the turbine or generator, thereby preventing costly repairs. The shaft deflection indicator provides a positive means of detecting excessive vibrations in a hydraulic turbine-generator shaft so that the cause can be investigated and the unit can be shut down, if necessary, to minimize damage.

* See "Control of Hydro Power — 1953," John Baude and T. F. Finley, Allis-Chalmers *Electrical Review*, Third Quarter, 1953.

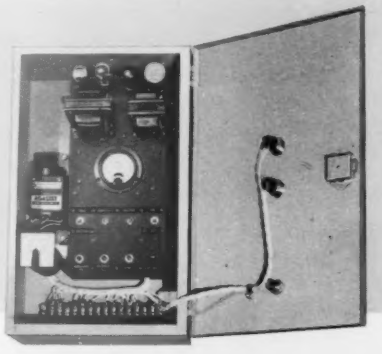
Experience has shown that a protective device to guard against excessive vibration must meet the following requirements:

1. Must be vibration sensitive, but should not be attached to, or bear on, the rotating element.
2. Must have high sensitivity and be adjustable to the characteristics of the unit.
3. Must incorporate an adjustable time delay to prevent relay operation from vibrations of short duration, such as those caused by ice passing through the turbine, or sudden load changes.
4. Should provide visible indication of normal operation, as well as operation during abnormal conditions.
5. Should operate on 120-volt or other station auxiliary power.
6. And should incorporate a built-in test circuit.

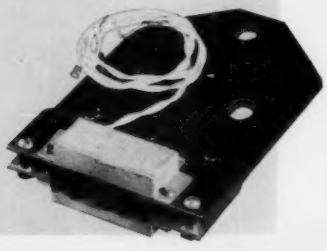
The first shaft deflection indicator of this type was built and applied to the hydroelectric unit shown in Figure 1 approximately four years ago.

The shaft deflection indicator, shown in Figures 2, 3, and 4, is essentially an application of the Wheatstone bridge. Two inductors like the one shown in Figure 4 are mounted on opposite sides of the generator shaft just below the lower bearing housing, as shown in Figure 5.

CONTROL ELEMENTS are all contained within one small cabinet. **(FIGURE 2)**



PERIODIC TESTS are easy to make because of convenient grouping. **(FIG. 3)**



INDUCTORS are securely attached to rigid mounting brackets. **(FIG. 4)**

The Wheatstone bridge circuit is shown in Figure 6. A small air gap is provided between each inductor and the shaft surface. A voltage is applied to these inductors by the shaft deflection indicator main control unit, which may be located at any point in the powerhouse. Since the impedance of the inductor circuits is matched, currents flowing in the inductors are equal, and give a zero indicator reading as long as the air gap between each inductor and the shaft remains equal.

However, should any vibration occur while the unit is in operation, the air gaps will become unbalanced and cause changes in the impedances of the circuit. This will result in a current flowing to the control cabinet and indicating unit, shown in Figure 3. If this current is greater than a predetermined amount, it will immediately operate the control unit itself, and the lower red light on the cabinet will light up, giving visual indication of the undue vibration. Should the vibration be of short duration, say 5 seconds, the relay will go back into a balanced condition and the light will go out. Should the vibration continue for a period longer than the time-delay relay setting, a second red light above the first goes on, indicating that vibration is continuing and that the unit should be investigated and the cause corrected immediately.

At the time the second red light operates, another circuit is energized. This second circuit can be used to operate an audible alarm system, or it can be interconnected with the powerhouse system of protective devices to shut down the unit completely.

The adjustable time-delay circuit was added after experience with the first installation revealed that vibrations of short duration sometimes resulted in unnecessary shutdowns. Since then, the device has been so successful throughout its four years of operation that an additional deflection indicator is now being applied on a hydro turbine-generator by this western utility.

Suitable switches, relays, contacts, etc., have been incorporated in the shaft deflection indicator to make it easy to install and operate. A sensitivity adjustment is provided so that the relay can be set to operate with a differential between the two air gaps of anywhere from 1 to 15 mils. Once set by the operator, it will give a signal when any vibration within its setting occurs, and then reset itself if the vibration disappears. Should the vibration continue beyond the setting of the time-delay relay, the alarm circuit will close. A double-throw switch permits setting the relay to either maintain the alarm circuit when once established or reset the relay automatically when the unit is shut down or when the vibration disappears. The relay can be used to operate other relays which perform operations in protecting and governing the generator and turbine.

The deflection indicator is economical both in original cost and in maintenance. When considered as a part of the hydraulic turbine-generator it protects, the deflection indicator increases equipment cost by only a small fraction of 1 percent. The only maintenance required is the replacement of three electronic tubes every 4000 hours.

The device can be applied regardless of whether the rotating equipment has a vertical or horizontal extended shaft. The inductors for indicating vibration should be mounted at a point where the shaft deflection, due to vibration, is likely to be most severe. But since it is not always possible to determine where this will be, the inductors are usually mounted at the most convenient location between the turbine and generator. A typical inductor installation is shown in Figure 5.

Successful and economical operation of hydroelectric plants on an unattended or semiattended basis requires that information about any possible malfunction be transmitted to the supervisory station. The shaft deflection indicator can now give supervisory stations valuable information available in no other way. It will undoubtedly become an important addition to the warning and protective devices previously available.

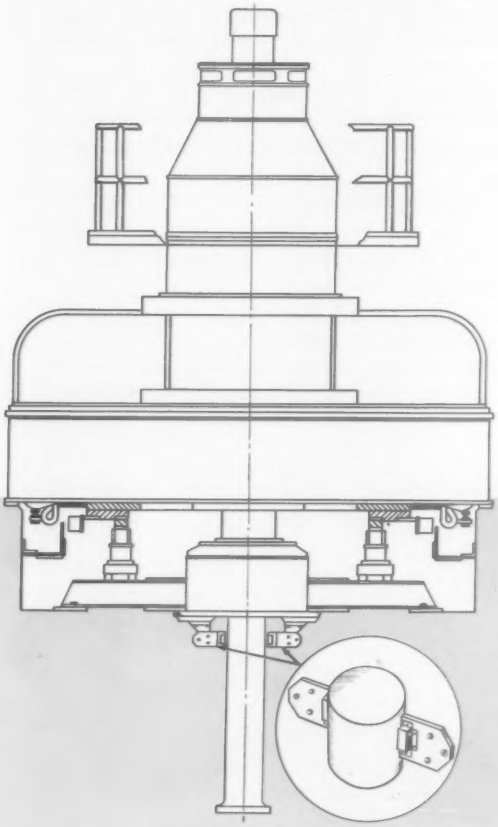
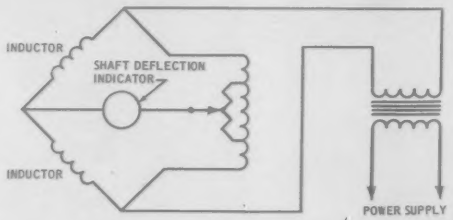


FIGURE 5



EXCESSIVE SHAFT VIBRATION causes inductor impedances to change, upsetting the balance of the circuit and causing the deflection indicator to signal a warning. **(FIGURE 6)**

RELIABILITY

In Large Circuit Breaker Operation Depends Upon

THIS BASIC DIFFERENCE

ALLIS-CHALMERS
PROGRESS IN
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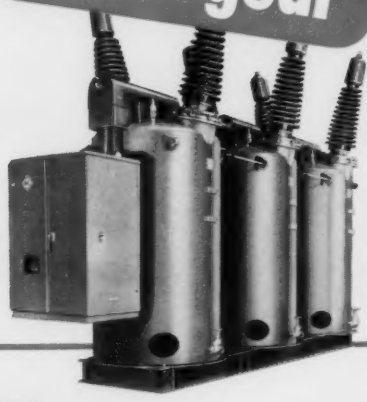
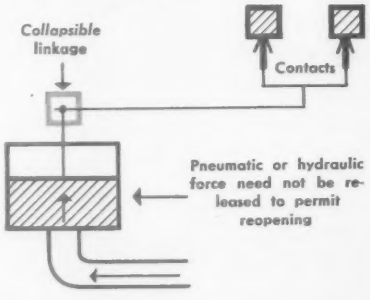


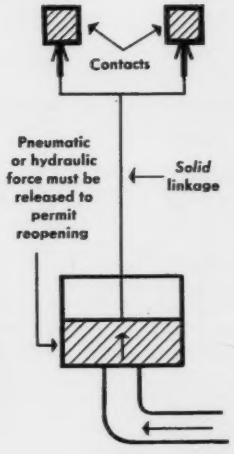
Allis-Chalmers *Mechanically Trip-Free* Mechanism

When opening after closing against a fault, the Allis-Chalmers operating mechanism does not require dumping of oil or air pressure. Trip coil simply releases a latch and the closing linkages collapse, allowing contacts to open at full speed. Operation is fully mechanically trip-free.



Other Operating Mechanisms

Air or oil pressure used to close contacts must be dumped — fast—to permit contacts to open. To do this takes a whole sequence of devices, including valves and solenoids. Everything must work perfectly. Otherwise breaker will be held closed or slowed in opening.



Opening the breaker when it closes against a fault, regardless of the position or condition of the closing mechanism, is the protective function of the breaker. To be fully protective under all circumstances, every one of your breakers should have a fully mechanically trip-free mechanism. For further details on what mechanically trip-free operation means to you, call your nearby Allis-Chalmers District Office or write Allis-Chalmers, Milwaukee 1, Wisconsin.

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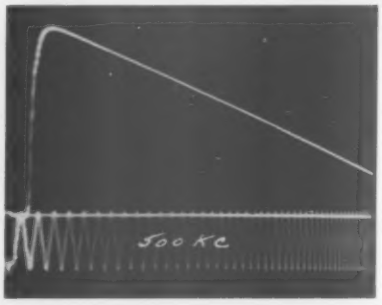
Proof of Performance for *Every* Standard Distribution Transformer



You know you get all the inherent insulation strength possible in an Allis-Chalmers distribution transformer. The oscillogram above — taken from a production line impulse test — proves it. It shows that all the production processes necessary to extend transformer life have been carried out. Not only distribution transformers with protective equipment, but conventional units are tested as well. This is Allis-Chalmers seventh year of production line impulse testing.

Every Allis-Chalmers distribution transformer gets a fast, efficient vacuum treatment to remove air bubbles in windings and oil. The process also assures complete oil impregnation of all fibrous insulation before the transformer leaves the factory.

How the Vacuum Process Works

The photo above shows the operation. While the core and coil unit is still hot from the dry-out oven, it is tanked and covered with hot oil. Then, immediately after final assembly, the vacuum draws out all moisture and any air bubbles locked within the transformer windings.

Many Steps Improve Transformers

This is just one of the many careful steps in design and manufacture that bring you dependable Allis-Chalmers distribution transformers. It means you can count on more transformer service years . . . more economy in transformer operating costs.

For further information call your nearby A-C district office or write Allis-Chalmers, Milwaukee 1, Wisconsin.

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